Ladle shroud as a mathematical function of Tundish Metallurgy

Ladle shroud can be considered a mathematical function of tundish metallurgy as far as the smooth tundish operation, steel production and quality is concerned. The primary function of the shroud are containment of teeming steel, preventing reoxidation by shielding the teeming stream from atmospheric contamination and preventing inclusions formation. With major advancement in design and technology the average life of the refractory shroud could be increased from 3 heats to more than 10heats. Thanks to the use of alumina-graphite refractories, design and coating technology.

High velocity of the stream is achieved owing to the presence of high turbulent kinetic energy. The jet flow of the ladle shroud determines the flow pattern in the pouring zone, which directly influences the formation of tundish open eye, tundish surface fluctuation, refractory erosion and trajectories of argon bubbles. With developments in recent times ladle shroud can even act as the flow control device for the tundish and has the potential to optimize the flow pattern inside the whole tundish.

A specially designed turbulence inhibitor commonly known as turbo stop which is placed inside the tundish above the impact pad is usually used to suppress the turbulence of the impinging jet and reduce bath surface fluctuations.

After evaluating the rate of atmospheric reoxidation and gas entrainment into the teeming steel it was observed that the amount of large inclusions increased by 2.5 times between the ladle and the tundish which is caused by the reoxidation of the ladle stream when refractory shroud was not used . The average oxygen content also decreased from 40–45 ppm to 20–25 ppm and the surface quality of the cold rolled sheet improved considerably as compared to non-shrouded casting practices. The contributing factors were the shape of the nozzle, height of the teeming from the bath level, the depth and the flow of molten steel in the ladle, stream turbulence, and physico-chemical properties of molten steel (*e.g.* viscosity and surface tension).

The Formation Tundish Open Eye

A jet of argon is used to seal the crevices between the shroud and the collector nozzle. But exceedingly high volume is undesirable. The higher flow rate of argon promotes the growth of larger gas bubbles. Fine bubbles are desirable for inclusion removal because large bubbles may result in turbulent flow which reduces the collision efficiency inside the shroud due to bubble coalescence. The rise of relatively large bubbles (3.0–5.0 mm) forms reversed flows around the ladle shroud when the flow enters the tundish pool. The formation of argon bubbles may sweep off the tundish slag which will lead to the formation of a tundish open eye (TOE).

TOE is detrimental as far as radiative heat losses, reoxidation of the liquid steel and nitrogen and oxygen pickup are concerned.

Misaligned or inclined shroud

When the ladle shroud and collector nozzle of the ladle shroud is slightly misaligned, a biased jet flow is formed which hits the tundish pool. Consequently, the turbulence is unevenly distributed, and steel-argon plume becomes biased with the formation an eccentric TOE. Jet exposure can give rise to intense slag-steel emulsification and slag entrapment, especially during ladle change.

In case of inclined shroud, airtight condition is depleted and chances of air infiltration increases. The misalignment of the ladle shroud is detrimental to both the shrouding performance (which includes air infiltration and formation of macro inclusions) and the flow pattern in the tundish. Flow control devices are recommended in the pouring zone to suppress the biased flow caused by the misalignment.

The pressure difference between the inner and outside of the ladle shroud is maximum at Pmax and is given by

$Pmax = qm .(W3-W1)/ A1$

(where A1 is the area of the ladle shroud. W1 and W3 represent the steel flow velocities of the collector nozzle and the ladle shroud respectively. qm and T are the mass flow rate and temperature of molten steel respectively).

This equation implies that a larger flow rate or a higher throughput can bring about a higher maximum pressure difference. As the casting speed has been at an increasing trend, higher through put rate will result in higher pressure difference. Therefore better sealing technique has to be employed to bear the pressure difference.

Three techniques can be implemented to minimize the air infiltration are: (1) injecting inert gas into the ladle shroud to compensate for the pressure difference, (2) argon curtain sealing to replace the absorbed air by argon; and (3) improving the sealing of the junction.

ladle shroud dipping inside the molten bath

The amount of submergence inside the tundish predominantly determines the surface fluctuations, slag-metal emulsification and air entrainment or reoxidation. Increasing the submergence depth of the ladle shroud dissipates the jet turbulence. Minimum shroud dipping is recommended to negate the above mentioned occurrences. However, the increased submergence depth asks for a deeper tundish pool so as to reduce the refractory erosion of the tundish bottom.

Operation of high-depth submergence serves the purpose of turbulence inhibitor, which lowers the surface turbulence and the slag entrainment.

Shroud also helps in the reduction of loss of metal temperature from the teeming stream, and the temperature loss was estimated to be 5 to 8°C.